As educators, we are continually designing new methods and procedures to enhance learning. During this process, good ideas are frequently generated and tested, but the extent of such activities may not be adequate for a full manuscript. Nonetheless, the ideas may be quite beneficial in improving the teaching and learning of physiology. *Illuminations* is a column designed to facilitate the sharing of these ideas (illuminations). The format of submissions is quite simple: a succinct description of about one or two double-spaced pages (less title and authorship) of something you have used for the classroom, teaching, lab, conference room, etc. You may include one or two simple figures or references. Submit ideas for inclusion in *Illuminations* directly to the Associate Editor in charge, Stephen DiCarlo (sdicarlo@med.wayne.edu).

**ANALOGIES FOR UNDERSTANDING STATISTICS**

Whether as educator or scientist, I always have difficulty in explaining statistics in a simple way to students or colleagues involved in biological studies. Biologists examine their results extremely critically and carefully choose the appropriate analytic methods depending on their scientific objectives. However, no such close attention is usually given to the choice of relevant statistical tools and to assessment of how statistical methods may influence the validity of the results. We thus encourage interdisciplinary science and we support collaboration between biologists and statisticians from the very beginning of a project.

This illumination describes a simple way to explain the limitations of statistics to scientists and students to avoid the publication of misleading conclusions.

Let’s consider a biological phenomenon to be observed. We will compare this biological event to a geometrical figure (for instance, a parallelepiped). Because biological processes are unknown and cannot be observed easily, we must first postulate that no geometrical figure (such as the parallelepiped) can be described directly by anybody.

Statistical tools help one to analyze experimental data that themselves describe the studied biological event. With this in mind, the different experimental designs or the different statistical tools (1, 3) available for scientists (t-test, ANOVA, regression, etc.) can be compared with different lights that illuminate the geometrical figures. Just as the biologists observe the biological processes that they are studying indirectly, the observers cannot see the geometrical figures that they would like to describe, but only their shadows.

The first point is that each experimental design or each statistical test allows a specific description of the studied biological event, and this description may differ from that provided by another experiment or another test. It is indeed well known that a researcher looking at the putative effect of a treatment by comparison with a control group can conclude that the effect of the treatment is significant or not depending on the experiment or on the statistical test that is used (3). In our comparison, the different shadows of the parallelepiped do indeed differ depending on the position of the lights. In other words, we can deduce only a specific part of the parallelepiped from the shadow depending on the position of the light. Moreover, the representation of the parallelepiped is more or less similar to the shape of the original figure. For instance, the shadow may be higher or smaller than the original figure with a light located beside or above the figure, respectively. Similarly, in biology, the difference between two groups of subjects (a control and an experimental group) may be amplified or reduced relative to the reality depending on the experimental design or the statistical method. In the first case, the probability of detecting false-positive effects is too high, and in the second case the probability of obtaining false-negative effects is too high (the statistical test does not allow the researcher to detect any significant difference; Fig. 1). This simple analogy emphasizes that scientists may use the wrong statistical techniques to analyze their data (1). It is just like a physician who uses the wrong drugs to cure his patients of an illness. If this is so, the scientist will overestimate or underestimate the treatment effect he is studying, just like the shape of the shadow, which may amplify or reduce the shape of the original figure (Fig. 1).

Even if the researcher uses the appropriate experimental design and the appropriate statistical method, s/he may be...
relationship of the lung and chest wall system. At most lung volumes, the recoil of the lung is inwardly directed, whereas the recoil of the chest wall is outwardly directed. When the two recoil forces are of equal magnitude, but in opposite directions, the lung and chest wall system is in dynamic equilibrium. The lung volume where this occurs is functional residual capacity (FRC). What follows is a description of a simple model that can demonstrate this phenomenon, as well as demonstrate active muscular inspiration and passive expiration. By changing the model slightly, the effect of a change in lung recoil, due to either pulmonary fibrosis or emphysema, can also be demonstrated. This model is based on the pulmonary ventilation teaching aids presented by Stockert (1, 2).

The model is constructed of four aluminum lab-frame rods, three clamp holders, a heavy base, a free-swinging thermometer clamp, and four rubber bands (Fig. 1A). When describing the assembled model (Fig. 1B), indicate that the left vertical rod represents 0% vital capacity (VC), the free-swinging rod in the middle represents the chest wall, and the right vertical rod represents 70% VC. Then, hold up two rubber bands that respectively represent the elastic recoil of the lung tissue and elastic recoil of the chest wall. Attach the rubber bands to the moveable “chest wall” such that the two rubber bands are pulling in opposite directions (Fig. 2A). The place where the chest wall is now positioned is FRC, with the elastic recoils of the lung and chest wall balancing each other.

To demonstrate an inspiration, physically move the bottom of the chest wall rod toward a larger lung volume (i.e., to the right, toward the 70% VC rod, Fig. 2B). The energy that is required to do this is analogous to the energy provided by the muscles of inspiration (i.e., the diaphragm and external intercostal muscles) during an inspiration. This will also stretch the rubber band representing the lung elastic recoil, which will pull back on the chest wall rod. To demonstrate a passive expiration, simply release the chest wall rod, and the chest wall returns to FRC (Fig. 2C). The energy that produces this movement is the stored energy in the stretched rubber band representing lung elastic recoil, and thus no muscular energy is needed during a passive expiration. More advanced demonstrations could indicate the recoil forces during an inspiration to a large lung volume (i.e., >70% VC), where lung and chest wall recoils would now both be directed inward, or during an active expiration to a lung volume less than FRC (i.e., to RV), where the chest wall recoil would increasingly oppose the decreasing lung volume.

By adding or changing rubber bands, pulmonary disease states can also be demonstrated with this model. Adding a second rubber band to increase elastic recoil of the lung would represent pulmonary fibrosis (Fig. 2D). In this case, FRC is reduced, and it is much more difficult to produce an inspiratory movement of the chest wall because of the increased lung elastic recoil. Removing the two lung recoil rubber bands and replacing them with a single, larger rubber band with less elastic recoil would represent emphysema (Fig. 2E). In this case, both FRC and the compliance of the lung are increased, making it easier to produce an inspiratory movement of the chest wall. A pneumothorax can be demonstrated by unhooking the rubber band representing the lung elastic recoil from the chest wall rod and holding it in position on the 0% VC aluminum rod (Fig. 2F). The rubber band will recoil inward, demonstrating a collapsed lung, while the chest wall rod will

unable to detect any significant difference between a control group and an experimental group. This may be due, for instance, to a low number of subjects per group. Sample size is indeed a key parameter that determines the power of the experimental design (2). For instance, it can be easily calculated using the t-test formula that the number of subjects per group increases when the difference we wish to detect is lower or similar to the intragroup variability due to technical and/or biological sources of differences (Fig. 2).

We can illustrate this problem by using lights with different powers (Fig. 3). Although the light induces a shadow similar to that of the original parallelepiped, this shadow may be black, gray, or even almost white if the light is of low power. In the last case, it would be impossible to observe the parallelepiped.

Similarly, scientists may be unable to describe the biological phenomenon they are looking at due to an inappropriate number of samples despite appropriate experimental design and appropriate statistical methods. This phenomenon may be compared with a physician who uses the right drug but gives the wrong dose of the drug.

We hope that this Illumination will constitute a helpful description of statistics. The goal is to reduce the number of scientific studies published that use statistical methodology incorrectly, as observed, for instance, in molecular biology (1).

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A SIMPLE MODEL ILLUSTRATING THE BALANCING FORCES OF LUNG AND CHEST WALL RECOIL

A difficult concept for students to understand is how the recoil forces of the lung and recoil forces of the chest wall balance each other to determine the relaxation pressure-volume
Fig. 1. Lung and chest wall recoil forces in unassembled (A) and assembled (B) form.

Fig. 2. Schema of the model, illustrating its use. See text for details.
be moved outward by the chest wall recoil, demonstrating unopposed chest inflation. Note that the rubber band representing the collapsed lung does not completely collapse to a zero volume; the maintained “inflation” of the “lung” during a pneumothorax represents the lung’s minimal volume.

This presentation is highly visual and easily demonstrates a difficult topic for students to understand. It has been used during lectures to students in medical, pharmacy, physician’s assistant, and physical therapy programs. Most students seem to like the demonstration, and I have received positive feedback from students in all programs. Once having viewed the demonstration, students seem to easily grasp this difficult concept.

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